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AUTHOR Foorman, Barbara R.; And Others
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AVAILABLE FROM Barbara Foorman, Department of Educational Psychology, College of Education, University of Houston, Houston, TX 77004
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ABSTRACT

In order to study children's strategies for solving geometric matrices similar to those in the Raven's Progressive Matrices, ninety 7-, 10-, and 13-year-old boys and girls were administered tests of auditory and visual memory, the Raven's, and geometric matrices. The matrices varied in number of elements (1 to 3) and number of transformations (0 to 2). The fact that the 10- and 13-year-olds increased their latency to solution with increased item complexity on correctly completed matrices suggests support for a two-component process of identification of elements and specification and execution of transformations. However, high error rates for all ages on one particular item type for incorrectly completed matrices suggested strategies which focused on specifying transformations to the exclusion of identifying elements or executing transformations. Solution of figural matrices for 10- and 13-year-olds appeared to place demands on both visual and auditory memory. (Author/MP)

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Developmental Differences in Strategies for Solving Figural Matrices

Barbara R. Foorman, University of Houston
Mary Carol Day, University of Houston*
Barbara Sadowski, University of Houston
Carol Hailes, University of Houston

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Abstract

In order to study children's strategies for solving geometric matrices similar to those in the Raven's Progressive Matrices, 90 7-, 10-, and 13-year-old boys and girls were administered tests of auditory and visual memory, the Raven's, and geometric matrices. The matrices varied in number of elements (1 to 3) and number of transformations (0 to 2). The fact that the 10- and 13-year-olds' increased their latency to solution with increased item complexity on correctly completed matrices suggests support for a two-component process of identification of elements and specification and execution of transformations. However, high error rates for all ages on one particular item type for incorrectly completed matrices suggested strategies which focused on specifying transformations to the exclusion of identifying elements or executing transformations. Solution of figural matrices for 10- and 13-year-olds appeared to place demands on both visual and auditory memory.

Developmental Differences in Strategies for Solving Figural Matrices

One way in which cognitive psychologists have contributed to understanding the form and content of mental abilities has been to construct cognitive process models of performance on standard psychometric tests (Sternberg, 1981). Recently Stone and Day (1981) constructed such a model of performance on figural matrix problems similar to those in the Raven's Standard Progressive Matrices (Raven, 1956). Stone and Day (1981) found significant increases in 11- and 14-year-olds' and adults' latencies to solution on these matrices with increases in the number of elements (1-3) and number of transformations (0-2), and they proposed that (at least) two component processes are involved in matrix solution: (1) Identification of elements and (2) Specification and execution of the transformation(s) relating elements.

Mulholland, Pellegrino, and Glaser (1980) had explained adult performance on geometric analogies in terms of a serial decomposition process into subpatterns and transformations of subpatterns. In investigating verbal analogical reasoning in 8- and 10-year-olds Goldman, Pellegrio, Parseghian, and Sallis (1982) attributed age and skill differences to the child's problem space for the

analogy task and possible differences in task understanding. Stone and Day's data also suggest developmental differences in processes and strategies underlying solution of figural matrices because the nonadditive increases in latency that resulted from the interaction of elements with transformations suggests a model of increased demands on working memory with increasing item complexity.

In an attempt to test the generalizability of a model of analogical reasoning proposed for adults (Sternberg 1977a, 1977b), Sternberg and Rifkin (1979) presented schematic drawings with separable attributes and with integral attributes to subjects between the ages of 8 and 19. Developmental differences in response latencies and error rates were explained in terms of different patterns of component processes operating in the two kinds of problems. In analogies with perceptually separable attributes change over age appeared due to consistency in use of strategy and component-operation latency and difficulty. However, in analogies with integral attributes developmental differences were attributed to these two processes as well as availability of component operations and strategies for combining multiple executions of the same component operation.

The Stone and Day (1981) matrices used in the present investigation were constructed to be similar to the Raven's

problems in the algorithms relating constituent cells; unlike some of the Raven's problems, the matrices did not require disembedding designs. In the present study the figural matrices were given to 7-, 10-, and 13-year-old boys and girls in an attempt to further clarify the nature of the processes underlying solution of geometric matrices. Since Stone and Day's older subjects had performed at ceiling on the matrices, adults were eliminated from this study and 7-year-olds were included in order to focus more specifically on developmental change in latency and accuracy of solution. The Raven's was again administered to see if a significant negative correlation between mean response time on the experimental matrices and number correct on the Raven's would appear with 7-year-olds and 10-year-olds, as it had with the 11-year-olds in Stone and Day's study. Moreover, tests assessing auditory memory and visual memory were administered. If the more complex items place greater demands on working memory, then one might expect a positive relationship between memory and accuracy and speed on more complex items. Finally, the Stone and Day study included only females. Male subjects were included in the present investigation to determine if there were any performance differences related to gender.

Method

Subjects

Subjects were 90 middle-class boys and girls, 30 each

from grades 2 (mean age 7;4), and 5 (mean age 10;5), and 8 (mean age 13;4). All of the children attended a Catholic school in Houston, Texas.

Tests

Measures of working memory. - Subjects were administered the Figural Intersection Test (Pascual-Leone, Note 1) and the Backward Digit Span (based on the expanded version of Wechsler, 1974 by Pulos, Note 2) as measures of visual and auditory memory respectively. The Figural Intersection Test (FIT) is a group administered paper and pencil test consisting of 43 test items, plus 6 introductory items. Each item consists of two sets of simple geometric shapes, a set on the right called the presentation set and a set on the left called the test set. The presentation set contains a variable number of shapes, physically separated from each other. The test set contains the same shapes as the presentation set, but arranged in an overlapping configuration so that there exists a common area of intersection, which is simultaneously inside all of the shapes. The task is to identify and mark the common area of intersection.

The Backward Digit Span (BDS) is individually administered and requires that sequences of numbers presented orally be said in reverse order. This version of the BDS has been expanded according to Pulos (Note 2) to include five trials at classes of difficulty ranging from

two to eight digits, similar to the format of the FIT. Subjects were scored on both the FIT and BDS according to the sum of the difficulty index of each trial passed. For example, passing all five trials with two and three overlapping figures on the FIT yields a score of 10 plus 15 or 25. Passing the same trials on the BDS as well as two trials of four-digit sequences yields a score of 25 plus 8 or 33. In addition to these separate scores of 25 and 33, a composite score of 29 based on the mean of the separate scores was derived to reflect combined visual-auditory memory.

Figural matrices. - The Raven's Standard Progressive Matrices, Sets A through E (Raven, 1956) were administered to each grade. Then Stone and Day's (1981) experimental matrices were administered. Each item type in Stone and Day's matrices represent the crossing of one to three elements with zero to two transformations. Geometric forms used were: triangle, rectangle, circle, hexagon, diamond, semicircle, plus sign, and minus sign. Transformations were: no transformation, addition of a form, expansion in size, and circular motion in a plane. For example, in one matrix there is a triangle in each cell of the top row which expands in size. In the second row the same transformation of expansion in size applies to a different element, a circle. In the third row the same transformation applies to an arrow. This matrix of one element and one

transformation is "true" because the last cell in the bottom row is completed with the correct element revealing the correct transformation. If a small arrow or a rectangle of any size were in the bottom righthand cell, the matrix would be "false." An example of a true matrix with three elements and no transformation is presented in the top of Figure 1. In the bottom of Figure 1 is a false matrix with two elements and one transformation.

Insert Figure 1 about here

Procedure

Subjects were administered tests in the following order: FIT, BDS, Raven's, and experimental matrices. The experimental matrices were individually administered in two random orders to each subject in two sessions, a training session of twenty matrices and the test session of 108 matrices (6 true and 6 false matrices representing each of the 9 item types). The first two slides served to demonstrate the equipment. When the child hit a "ready" button with his or her non-preferred hand a 1 1/2 second interval timer was triggered. After the interval a slide depicting one of the matrices was released into a carousel projector and projected against a screen. A millisecond timer was activated upon the release of the slide. The child was instructed to "see what's happening in each row"

of the puzzle and to hit with his or her preferred hand a blue pad on a response bar if the puzzle was completed correctly and a yellow pad if the puzzle was not. As soon as the response bar was struck the timer was deactivated and the experimenter took note of the latency and correctness of solution.

In addition to the two slides used to demonstrate the equipment there were eighteen training slides representing one true matrix and one false matrix of each item type. If a child made an error on any of these practice items corrective feedback was given by projecting the slide again and asking the child to explain what was happening in each row. Training sessions lasted about twenty minutes and were followed one to three days later by the test session with the 108 experimental matrices. The first ten slides of the experimental set were the same slides shown in the second half of the training session. No feedback was given during the test session. Subjects were reminded to "see what's happening in each row" and to say "right" or "wrong" as they hit the blue or yellow side of the response bar. Test sessions lasted from twenty to fifty minutes per subject with the average being thirty minutes. For no subject did a session have to be discontinued.

Results

3 (grade) x 2 (sex) x 3 (number of elements) x 3 (number of transformations) mixed ANOVAs were performed on

number of correct responses and on mean correct and incorrect response time for true and for false matrices separately. Response times which were more than two standard deviations above or below the mean of a subject's response times for each item type were eliminated. Eliminations never exceeded six percent of the responses on an item type for any grade. Mean numbers correct and mean response time on true and false item types are presented in Tables 1 and 2 for each grade.

Insert Tables 1 and 2 about here

Analyses of Variance on Accuracy and Response time

Grade was significant in the ANOVAs both on accuracy and on response time for true matrices, $F(2,84)=15.14$, $p<.001$ and $F(2,84)=3.83$, $p<.05$ respectively. However, grade was significant only in the analysis of accuracy for false matrices, $F(2,84)=7.66$, $p<.001$. Scheffé tests ($\alpha=.05$) indicated that fifth and eighth graders made significantly more accurate responses than second graders. Scheffé tests ($\alpha=.05$) also indicated that fifth graders were significantly slower in responding than the older or younger subjects. There was no significant main effect or interaction due to sex. Significant within-subjects effects are summarized below for true and for false matrices separately.

Insert Tables 3 and 4 about here

True matrices. - The analysis of number of correct responses yielded the following significant effects: transformation, $F(2,83)=28.48$, $p<.001$; grade x transformation, $F(4,166)=4.03$, $p<.01$, and grade x element, $F(4,166)=3.51$, $p<.01$. The significant main effect of transformation indicates that accuracy decreased as the number of transformations increased; indeed, the linear component of the transformation effect was significant, $F(1,84)=57.25$, $p<.001$. However, the grade x transformation and the grade x element interactions reveal that the effect of complexity was greater for the second graders than for the fifth and eighth graders. With increasing complexity (especially in the number of transformations), the accuracy of the second graders decreased more than the accuracy of the older groups, resulting in a larger difference between the youngest and older groups for the more complex items (e.g., 55%-66% correct versus 86%-88% correct).

Similar significant effects appeared in the analysis of response times: transformation, $F(2,83)=59.63$, $p<.001$; element, $F(2,83)=45.36$, $p<.001$, transformation x element, $F(4,81)=6.37$, $p<.001$, and grade x transformation, $F(4,166)=6.43$, $p<.001$. Response times increased as the number of elements increased and as the number of

transformations increased. For both transformations and elements there was a significant linear trend, $F(1,84)=105.62$, $p<.001$, and $F(1,84)=91.68$, $p<.001$, respectively.

The transformation x element interaction is based on a deviation in the trend towards longer response times for more complex items. For both one and two element matrices, response times increased as the number of transformations increased. In contrast, for three element items, response times increased between zero and one transformation but then remained the same for the two transformation items. Perusal of the means in Table 2 indicates that the second graders, whose response times were shorter for two transformation-three element items than for one-transformation-three element items, were primarily responsible for this deviation.

The grade x transformation interaction highlights the difference in the effect of more transformations on response times for second graders and for fifth and eighth graders. The response times of the two older grades increased with more transformations. The response times of second graders increased from zero to one transformation (from 5.14 to 7.95 seconds) and then decreased from one to two transformations (7.95 to 6.15 seconds). The second graders' decrease in response times is particularly interesting in light of their corresponding decrease in

accuracy.

False matrices. - The analysis of number of correct responses on the false matrices yielded the following significant effects: transformation, $F(2,83)=76.62$, $p<.001$; element, $F(2,83)=38.52$, $p<.001$; transformation x element, $F(4,81)=12.22$, $p<.001$; and grade x transformation x element, $F(8,162)=3.13$, $p<.01$.

The main effects of transformation and of element indicate that accuracy decreased as the number of transformations and the number of elements increased. The transformation x element interaction, graphed in Figure 2, appears to be based on the atypical performance on the one transformation matrices, that is, on the unusually low performance on the one transformation-three element items and (to a lesser extent) on the one transformation-one element items.

Insert Figure 2 about here

Note that for the zero and two transformation matrices there was a trend towards decreased accuracy with more elements. For the one transformation items, accuracy on the one element matrices was lower than accuracy on the two element matrices, and, in addition, accuracy on both the one and three element matrices was lower than accuracy on the two transformation matrices with one and with three

elements. This suggests that something unusual is happening with the one transformation matrices with one and with three elements.

Finally, the grade x transformation x element interaction is presented in Figure 3.

Insert Figure 3 about here

The interaction seems to be based on the greater decrease between one and three elements on the zero transformation matrices for the second graders than for the older groups; the transformation x element pattern of correct responses is quite similar for the three grades (and is supported by significant element x transformation interactions found in ANOVAs performed within grade).

The following effects were significant in the analysis of response times on false matrices: transformation, $F(2,83)=42.78$, $p<.001$; element, $F(2,83)=67.21$, $p<.001$; transformation x element, $F(4,81)=4.05$, $p<.01$, grade x transformation, $F(4,166)=3.60$, $p<.01$, and grade x transformation x element, $F(8,162)=2.57$, $p<.05$.

As was found for true matrices, response times increased as number of elements increased and as number of transformations increased. The transformation x element interaction indicated that the time required to respond to an additional transformation increased as the number of

elements increased, and that the time required to respond to an additional element increased as the number of transformations increased.

Figure 4 depicts the three-way interaction of grade,transformation, and element and serves to clarify the grade x transformation interaction as well.

Insert Figure 4 about here

Response times for the second graders increase between zero and one transformations, but then remain essentially the same from one to two transformations, especially for the two and three element matrices. Apparently, there is a point in increasing complexity where the second graders stop processing the additional elements or transformations. Response times for the fifth graders increased with additional transformations and with additional elements. The pattern was similar for the eighth graders with the exception of the one transformation-three element matrices, which had a lower response time than the zero transformation-three element matrices. As was the case with accuracy, it was again performance on this particular matrix type that deviated from the general trend.

Regression and Correlational Analyses

To understand the relationship between elements and transformations for true and for false matrices a

regression was computed for each grade where response time was predicted by forced-choice entry of: the linear trend in elements, the quadratic trend in elements, the linear trend in transformations, the quadratic trend in transformations, and the interactions of these trends. For true and false matrices the amount of total variation in response time accounted for by these trends was: 9% and 14% for second grade; 20% and 18% for fifth grade; and 24% and 23% for eighth grade. For fifth and eighth grades predictability clearly lay with the linear trend in elements and the linear trend in transformations (α=.001): $F(1,232)$=27.19 and 47.64 for fifth grade true matrices and 30.83 and 28.26 for fifth grade false matrices; $F(1,232)$=41.79 and 61.26 for eighth grade true matrices and 54.99 and 43.14 for eighth grade false matrices.

However, in the second grade such strong linearity was evident only in elements for false matrices, $F(1,232)=39.19$, $p<.001$. In sum, for fifth and eighth graders there was a strong tendency for response time to increase as the number of elements increased from one to three and the number of transformations increased from zero to two. For the second graders this strong tendency was apparent only in elements for false matrices.

The role of visual and auditory memory in figural matrix performance was examined through regression and correlational analyses. For each grade regressions were

computed for true and for false matrices where response time summed across the nine item types was predicted by forced-choice entry of Figural Intersection Test (FIT) and Backward Digit Span (BDS) scores. The range of FIT and BDS scores was restricted for the second grade but ranges and variances were comparable for fifth and eighth grades. For true matrices the FIT accounted for 10%, 9%, and 16% of total variation in second, fifth, and eighth grade response times while the BDS accounted for less than 1%, 10%, and 8% respectively. In the eighth grade the contribution of the FIT was significant, $F(2,27)=5.73$, $p<.025$. Moreover, regressions computed on eighth graders' response times for each true item type revealed that the contribution of FIT was significant in all but one of the item types with one and two transformations. In short, the visual measure of working memory -- the FIT -- predicted variation in response times on complex item types in true matrices for the oldest subjects.

However, for false matrices neither FIT nor BDS contributed significantly to variation in summed response times. Percentages for the FIT were: 7%, 10%, and 6% for second, fifth, and eighth grades. For BDS percentages were: less than 1%, 9%, and 12%.

Intercorrelations within grade were obtained between scores on the FIT, BDS, and number correct on true and false matrices. There were significant and strong

correlations between the composite FIT/BDS score and number correct on true and false matrices for fifth graders (r=.88, p<.001 and r=.81, p<.001 respectively) and on false matrices for the eighth grade (r=.53, p<.001). The FIT alone correlated moderately with number correct on false matrices for eighth grade (r=.50, p<.01) as well as weakly to moderately with number correct on the Raven's Standard Progressive Matrices for eighth and fifth grade (r=.34, p<.05 and r=.45, p<.01 respectively). The relationship between performance on the Raven's and performance on the figural matrices was weak (essentially zero), in contrast to the significant correlation (r=.66, p<.001) in fifth graders in the Stone and Day (1981) study.

Discussion

These data support the hypothesis of developmental differences in accuracy and latency to solution on figural matrices. Second graders were less accurate than fifth and eighth graders and fifth graders were slower than eighth graders. Second graders' response times did increase on true matrices with one, two, and three elements and no transformations and on one and two element matrices with one transformation. However, as matrix complexity increased beyond this point, response times decreased and errors increased.

These findings generally support Stone and Day's (1981) results with fifth and eighth graders and adults

with three exceptions. One, fifth and eighth graders in the present investigation made more errors (possibly due to increased subject variability in the present study with 30 male and female subjects per grade in contrast to the twelve female subjects per grade in the Stone and Day study). Two, there was a significant element x transformation interaction for accuracy in false matrices but not for true matrices. Three, in the present study the effect of transformations in true matrices appeared to be greater than that of elements. Four, although the linear trend in elements and the linear trend in transformations predicted fifth and eighth grade response times better than interactions of these polynomials, the resulting 18% to 24% of explained variation was markedly less than the 74% accounted for in the linear model in the Stone and Day study.

Several of these exceptions appear to be a consequence of the inclusion of second graders in the present study. For these youngest subjects an increase in transformations signaled a decrease in accuracy, and with increasing complexity the trend towards increased response time was curtailed. The difference between the second graders' and older subjects' performance on figural matrices appears related to strategy use. The fifth and eighth graders' performance, at least for true matrices, suggests a strategy consistent with Stone and Day's (1981) model of

(at least) two component processes for solving matrix problems: First, identification of elements in the rows of the matrix; second, specification and execution of transformations of elements across constituent cells. It takes time to identify elements and time to specify the transformations that relate constituent cells. The fact that second graders' processing time stopped increasing on true matrices involving one transformation with three elements or two transformations suggests a limited strategy. The strategy could account for up to three elements with no transformations or up to two elements with one transformation but no more. Matrices of greater complexity posed demands beyond the scope of the second graders' strategy. Hence their relatively fast responses but high error rate. In fact, five out of thirty second graders developed a response bias on at least one of the item types containing one or two transformations. Three of these five decided that all matrices with two transformations were wrong. In contrast, no response biases were evident in fifth or eighth grade.

In contrast to the second graders in this study, the fifth and eighth graders' increase in response time with the addition of an element and the addition of a transformation supports for these older subjects a strategy of sequential, exhaustive determination of the elements and of the transformations in each matrix. But what about the

fact that the linear model in the present study accounted for only 18% to 24% of variation in fifth and eighth grade response times in contrast to 74% in Stone and Day's? A possible explanation for this difference is suggested by the one item type that posed special problems for all grades.

The problematic item type was false matrices with one transformation and three elements. Error rates were unusually high, ranging from 40% to 46%, and eighth graders' response times were quite fast. Close examination of these particular matrices suggested two reasons for such a high error rate. One reason was that in one matrix the transformation was perceptually misleading. The transformation involved was expansion in size. In the bottom row a square with a dash and a triangle in it increased in size from the left cell to the middle. The matrix was falsely completed with a square the same size as the one in the left cell but because of the slightly larger boundaries of the added piece the square looked larger. Such a perceptual "pull" due to ecological factors creates what Sternberg and Rifkin (1979) call an analogy with "integral attributes," where the attribute of size is integral to the dimensions of the cell (i.e., cannot be nullified). Sternberg and Rifkin (1979) suggest that correct solution of such analogies require more component processes than analogies with perceptually separable

attributes.

The second reason for such a high error rate on false items with three elements and one transformation was that in two out of the six matrices the falseness was due to a change in one of the elements irrelevant to the transformation. In these analogies the attributes were clearly perceptually separable. The fact that error rates were so high for all subjects while response latencies were not (and were, in fact, quite low for eighth graders) suggests a possible short-cutting of the two-component strategy. That is, subjects might have exhaustively identified elements and specified transformations for only the top row. By the third row, it is possible that only the element undergoing transformation was scrutinized. In fact, the instructions to "see what's happening" might have encouraged such a focus on the transformation. Consequently elements not undergoing transformations would be considered less important and a change from a semicircle to a hexagon in the bottom row would not be noticed. Such a pattern is similar to Sternberg's notion of "self-termination" (Sternberg and Nigro, 1980). That is, subjects scan answer options in a top-down fashion until the minimum number of criteria for acceptability are met.

The insight we gain from subjects' possible strategy for processing this one item type is helpful in understanding the high degree of nonadditivity in response

times in the present study. As expected, increasing item complexity did not result in simple additive increases in response time. The significant transformation x element interactions for true and false matrices indicated that the time required to process a transformation increased with the addition of an element and that the time required to process an element increased with the addition of a transformation. Measures of auditory and visual memory (i.e., the BDS and FIT) were included in the present study in an attempt to predict the greater (and nonadditive) demands of more complex items on working memory. FIT scores did significantly predict eighth grade response times on complex true item types but the relationship was positive. That is, as FIT scores increased response times on complex true items increased (with accuracy near ceiling). Such a pattern suggests that with respect to latency to solution the FIT is tapping reflectiveness. However, with respect to accuracy of solution some support for the working memory hypothesis can be seen by the strong relationship between the composite measure of auditory and visual memory (BDS/FIT composite) and number correct on true and false matrices for eighth graders.

The failure of BDS and FIT to account for much variation in figural matrix performance is not so surprising. The assumption underlying the working memory hypothesis had been that as the number of elements and

transformations increased, processing time would have to be devoted to maintaining the accumulated information in working memory, thereby increasing total time for problem solution. But our examination of one item type suggested that speed of solution, at least in the context of this study, was not necessarily reflective of the snowballing of information to be retained in memory. Instead, seemingly simple items in terms of numbers of transformations and elements could become cognitively complex in light of subtle perceptual attributes. Future research on figural matrices needs to be sensitive to the characteristics defining item complexity as well as the inadvertent encouragement of self-terminating strategies for problem solution.

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Table 1

Mean Number of Correct Responses on True and False Item Types for Each Grade

	Item Type									
	Zero Transformation			One Transformation			Two Transformation			
Grade	1E	2E	3E	1E	2E	3E	1E	2E	3E	Total
True items:										
2.....	5.53	5.60	5.56	4.66	4.56	4.30	3.96	3.66	3.33	4.57
5.....	5.83	5.93	5.96	5.50	5.46	5.70	5.13	5.20	5.23	5.55
8.....	5.73	5.95	5.90	5.53	5.50	5.30	5.30	5.20	5.13	5.50
Total...	5.70	5.83	5.81	5.19	5.19	5.10	4.80	4.69	4.55	
False items:										
2.....	5.23	4.90	3.96	3.70	4.73	3.33	4.23	3.83	3.93	4.20
5.....	5.56	5.60	5.06	4.73	5.13	3.50	4.83	4.40	4.29	4.79
8.....	5.67	5.60	5.30	4.50	4.73	3.65	4.63	4.30	4.33	4.75
Total...	5.49	5.37	4.78	4.31	4.87	3.50	4.57	4.18	4.19	

Note.- E = element. The range of correct responses on an item type is 0 to 6.

Table 2.

Mean Response Time in Seconds on Correct Responses for True and False Item Types at Each Grade

	Item Type									
	Zero Transformations			One Transformation			Two Transformations			
Grade	1E	2E	3E	1E	2E	3E	1E	2E	3E	Total
True items:										
2.....	4.02	4.63	6.78	7.17	8.95	7.73	6.02	7.08	5.35	6.41
5.....	3.91	5.15	7.37	6.11	7.67	9.87	8.25	10.38	11.04	7.75
8.....	2.97	3.74	5.52	4.44	5.66	7.20	5.90	7.23	8.03	5.63
Total..	3.63	4.51	6.56	5.91	7.43	8.27	6.72	8.23	8.14	
False items:										
2.....	4.34	5.23	7.12	4.74	6.06	7.85	5.48	6.34	7.90	6.12
5.....	4.75	5.61	7.40	6.20	6.52	9.45	7.11	9.01	12.07	7.57
8.....	3.47	4.18	5.66	4.29	4.98	5.38	5.40	6.83	8.54	5.41
Total..	4.19	5.01	6.71	5.08	5.85	7.56	6.00	7.39	9.50	

Note. - E = element

Table 3

Wilks's λ, Multivariate F Ratio, Univariate F Ratio on Significant Trends, Degrees of Freedom, and Probability Levels for Within Subjects Significant Effects of Transformations, Elements, and Interactions on Response Time and Accuracy for Correct Responses on True Matrices

Predictor Variables	Wilks's λ	DF	F ratio	P
Accuracy:				
Transformations.....	.5930	2,83	28.48	<.001
Linear		1,84	57.25	<.001
Elements.....	.9679	2,83	1.37	N.S.
T*E.....	.9035	4,81	2.16	N.S.
Grade x T.....	.8301	4,166	4.03	<.01
Linear		2,84	8.01	<.001
Grade x E.....	.8501	4,166	3.51	<.01
Linear		2,84	6.85	<.01
Response time:				
Transformations.....	.4104	2,83	59.63	<.001
Linear		1,84	105.62	<.001
Quadratic		1,84	7.32	<.01
Elements.....	.4778	2,83	45.36	<.001
Linear		1,84	91.68	<.001
T*E.....	.7608	4,81	6.37	<.001
Grade x T.....	.7495	4,166	6.43	<.001
Linear		2,84	13.41	<.001
Grade x E.....	.9078	4,166	2.06	N.S.

Note.- Grade was significant for both accuracy and response time, $F(2,84)=15.14$, $p<.001$ and $F(2.84)=3.83$, $p<.05$ respectively.

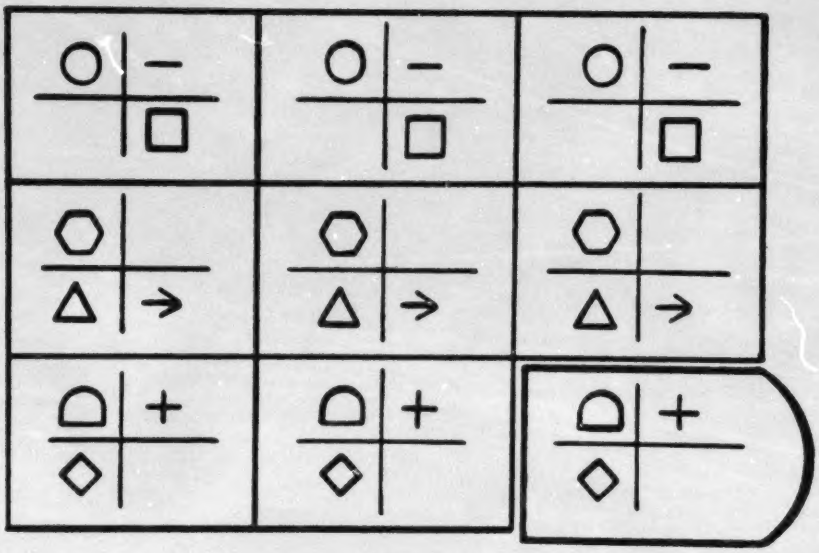
Table 4

Wilk's λ, Multivariate F Ratio, Univariate F Ratio on Significant Trends, Degrees of Freedom, and Probability Levels for Within Subjects Significant Effects of Transformations, Elements, and Interactions on Response Time and Accuracy for Correct Responses on False Matrices

Predictor Variables	Wilks's λ	DF	F ratio	p
Accuracy:				
Transformations....	.3513	2,83	76.62	<.001
Linear		1,84	94.35	<.001
Quadratic		1,84	52.74	<.001
Elements.....	.5186	2,83	38.52	<.001
Linear		1,84	57.13	<.001
Quadratic		1,84	32.13	<.001
T×E.....	.6236	4,81	12.22	<.001
Grade x T	.9407	4,166	1.29	N.S
GrxTxE.....	.2415	8,162	3.13	<.01
Response time:				
Transformations....	.4929	2,83	42.78	<.001
Linear		1,84	83.01	<.001
Elements.....	.3817	2,83	67.21	<.001
Linear		1,84	135.99	<.001
Quadratic		1,84	24.46	<.001
T×E.....	.8331	4,81	4.05	<.01
Grade x T.....	.8467	4,166	3.60	<.01
Linear		2,84	7.56	<.001
Gr x T x E.....	.7875	8,162	2.57	<.05

Note.- Grade was significant for accuracy, $F(2,84)=7.66$, $p<.001$.

Fig. 1. - Examples of the experimental matrices; Top: A "true" matrix with three elements and zero transformations; Bottom: A "false" matrix with two elements and two transformations.



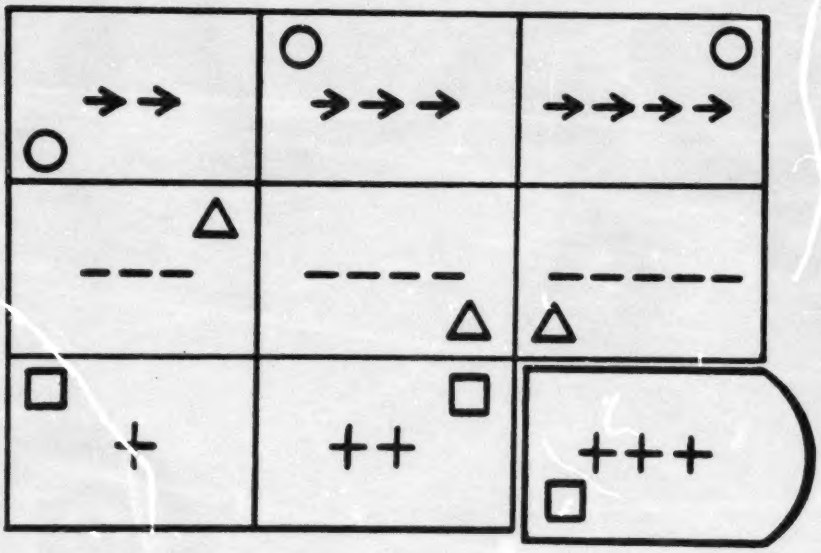


Figure 2

Interaction of Transformations x

Elements for Mean Number Correct on False Matrices

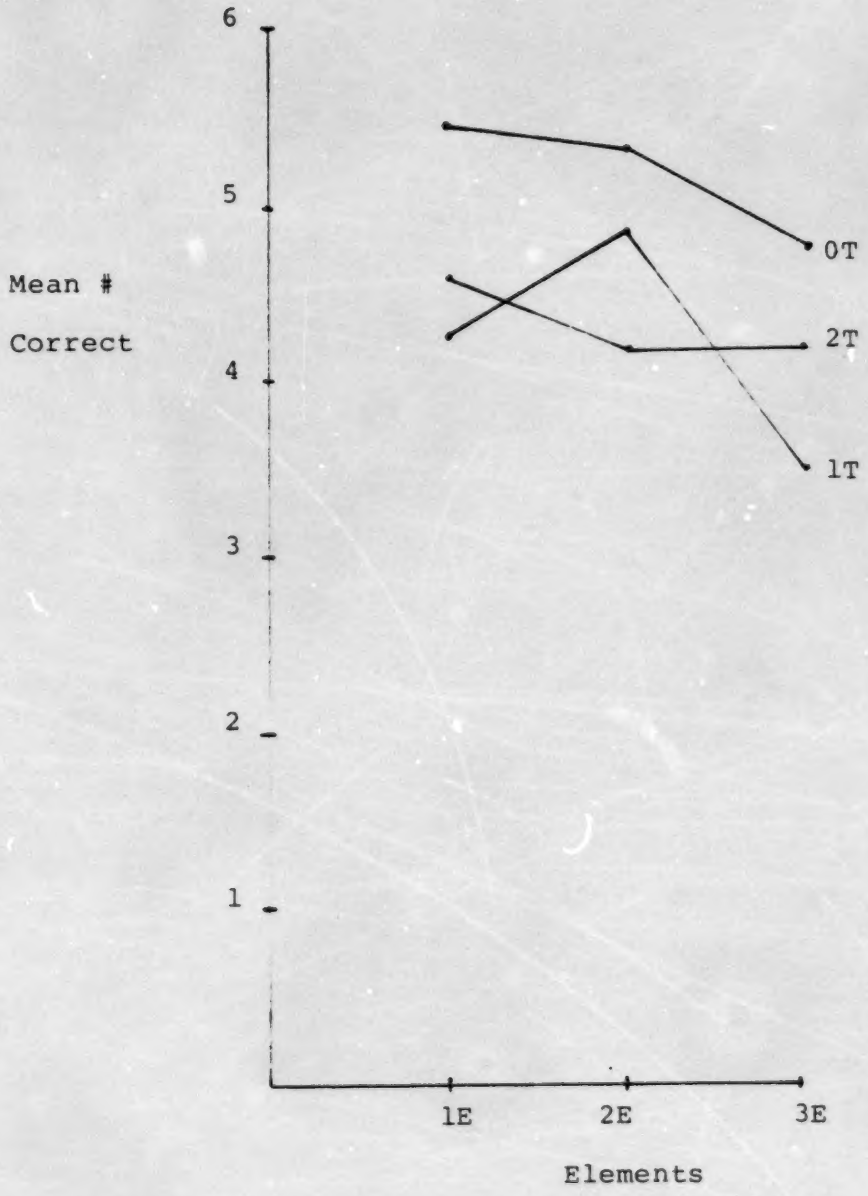


Figure 3

Grade x Transformation x Elements Interaction

for Accuracy on False Matrices

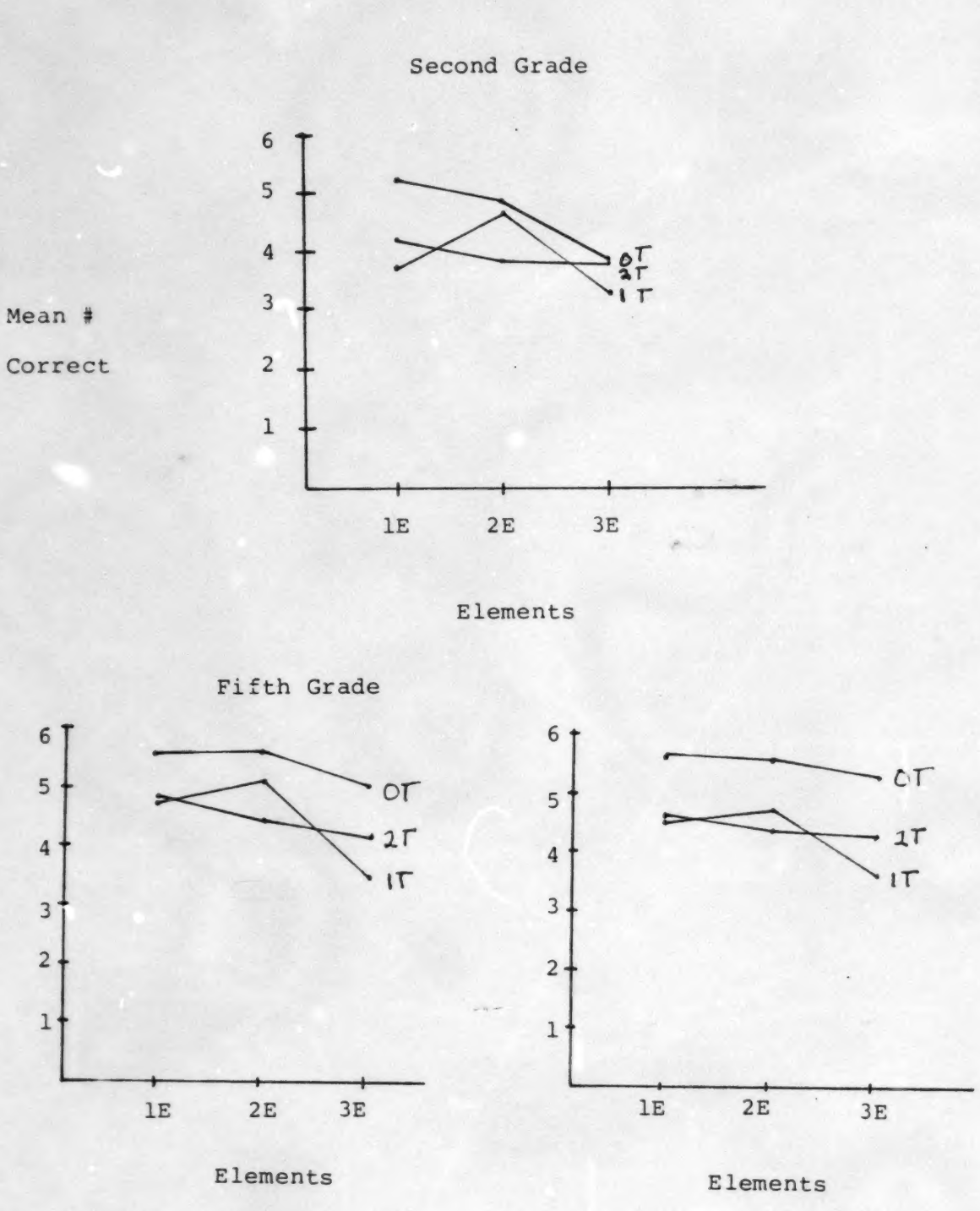


Figure 4
Grade x Transformations x Elements Interaction
for Response Time on False Matrices